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14. ABSTRACT
The focus of this project is to develop a process for constructing two-dimensional (2D) photonic crystals, which will be amenable to commercialization. Our approach has been to utilize nanochannel glass (NCG), which consists of a 2D hexagonal arrays of cylindrical voids that traverse the entire thickness of the glass. A 2D photonic can be realized with NCG if high index materials with good transmission properties can be introduced into the channels. This is the primary mission and focus of this project. In addition, e-beam lithography techniques are also being utilized to construct prototype two-dimensional photonic crystals that operate in the UV to low IR wavelength region of the light spectrum. The primary discoveries of this work have been theoretical modelling of gas flows in nanoscale structures and models for the formation of novel nanoparticles and nanowires in high aspect ratio structures. The findings of this work suggest that novel chemical sensors could be constructed with channel glass where nanoparticles or nanowires with specific properties have been formed within the channels. In terms of the ultimate goal of the project, 2-D photonic crystals

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Progress/Abstract

The focus of this project is to develop a process for constructing two-dimensional (2D) photonic crystals, which will be amenable to commercialization. Our approach has been to utilize nanochannel glass (NCG), which consists of a 2D hexagonal arrays of cylindrical voids that traverse the entire thickness of the glass. A 2D photonic can be realized with NCG if high index materials with good transmission properties can be introduced into the channels. This is the primary mission and focus of this project. In addition, e-beam lithography techniques are also being utilized to construct prototype two-dimensional photonic crystals that operate in the UV to low IR wavelength region of the light spectrum. The primary discoveries of this work have been theoretical modelling of gas flows in nanoscale structures and models for the formation of novel nanoparticles and nanowires in high aspect ratio structures. The findings of this work suggest that novel chemical sensors could be constructed with channel glass where nanoparticles or nanowires with specific properties have been formed within the channels. In terms of the ultimate goal of the project, 2-D photonic crystals based on nanochannel glass, the final conclusion is that nanochannel glass is not an appropriate foundation with which to construct 2D photonic crystals.

1. Project Overview

The focus of this project is to develop a process for constructing two-dimensional (2D) photonic crystals, which will be amenable to commercialization. Our approach has been to utilize nanochannel glass (NCG), which consists of a 2D hexagonal arrays of cylindrical voids that traverse the entire thickness of the glass. A 2D photonic can be realized with NCG if high index materials with good transmission properties can be introduced into the channels. This is the primary mission and focus of this project. In addition, e-beam lithography techniques are also being utilized to construct prototype two-dimensional photonic crystals that operate in the UV to low IR wavelength region of the light spectrum.

2. Progress

2.a. Differentially Pumped Plasma Enhanced Chemical Vapor Deposition of Oxides in Channel Glass

A model for the transport of gases down nanochànnels (Fig. 1) was developed in order to determine the optimal conditions for introducing optical materials into two-dimensional nanochannel glass arrays.The vertical axis of the plot in Fig. 1 is the transport flux as a function of channel diameter and differential pressure across the nanochannel samples. This model assisted us in explaining the formationof nanoparticles in channels during deposition (Fig. 2). These results have been published in the Journal of Applied Physics.

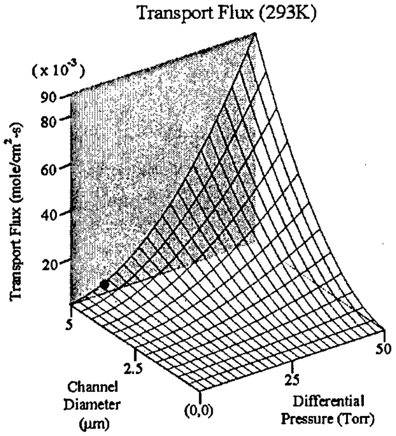

Figure 2, McIlroy et al.

Figure 1. Transport flux down for differentially pumped substrates as a function of channel diameter and differential pressure (Ref. 1)

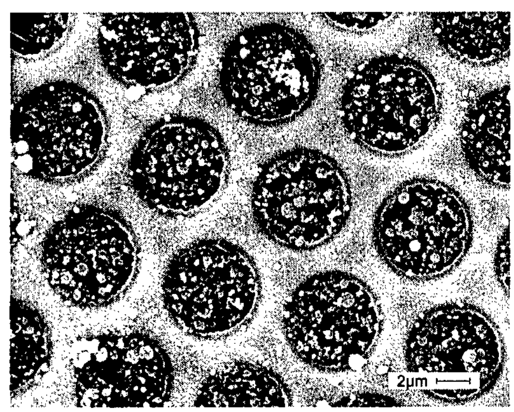

Figure 2. The formation of iron oxide nanoparticle in channel glass. (Ref. 1).

Based on this study it was concluded that an alternative method for introducing high index materials into nanochannel glass would need to be developed.

2.b. Atomic Layer Deposition Modification of System

The differential pumped deposition system has been successfully modified such that high index materials can now be deposited by atomic layer deposition (ALD). This system can deposite high index oxides such as tantalum oxide and hafnium oxide. Displayed in Fig. 3 is the complete system that includes computer controlled gas delivery and sample heating. Displayed in Fig. 2 is a close-up of the chamber. The system is completely automated and allows precise control of the thousands of cycles needed to deposit 100 nm-plus films of of high index oxides.

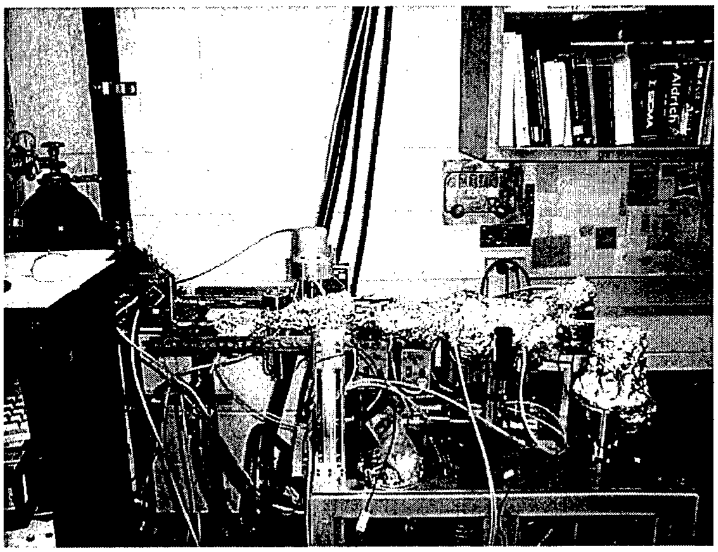

Figure 3. The current configuration of the deposition system for producing 2-D photonic crystals based on nanochannel glass provided by the Naval Research Laboratory.

2.c. Results of Atomic Layer Deposition of Oxides in Channel Glass

We have discovered that we can form KCl nanowires into channel glass. The first tests were performed without differential pumping across the channels. The results are shown below in Fig. 4, which shows the formation of single crystal KCl nanowires. We are in the process of exploring their photoluminescence properties. The ability to grow material in the channels without differential pumping suggests that when included we will succeed in filling the channels and therefore obtain our goal of realizing 2D photonic crystals. The distribution of the nanowires is centered on 240 nm and with a standard deviation of 50 nm. The process has been modified such that HCl can be used instead of tantalum chloride. This greatly simplifies the process and opens up the use of these nanowire/nightvision substrates for enhanced visualization or functionalization of night vision goggles. A paper entitled "Potassium Chloride Nanowires Grown inside Micro-channel Array Glass Using Atomic Layer Deposition" has been submitted for publication.

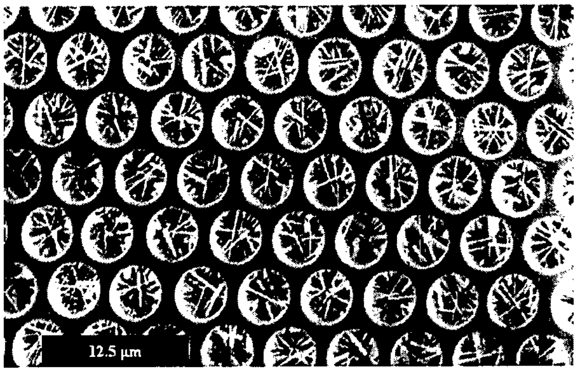

Figure 4. A scanning electron microscope imageof KCl nanowires inside microchannel glass.

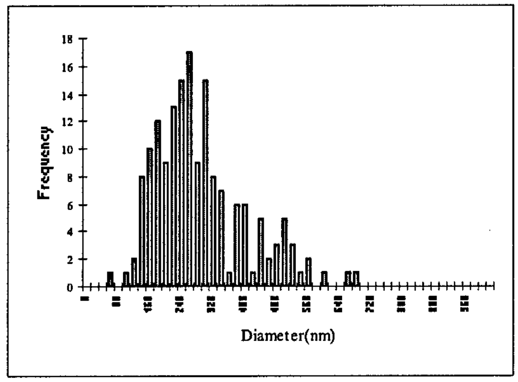

Figure 5. Diameter distribution of KCl of the sample in Fig. 4.

3. Future Plans

Have begun to design and process development to construct two dimensional photonic structures using nanowires, thereby eliminated the need for using nanochannel glass. These devices would be based on GaN nanowires and would be integrated with Si technology. The concept is illustrated in Fig. 6 where instead of an array of voids the array would consist of GaN nanowires.

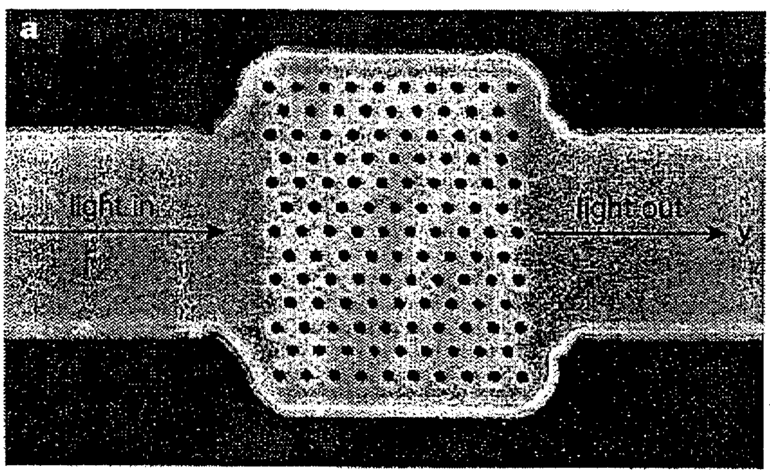

Figure 6. A conceptual image of future fabrication of 2-D photonic crystals using GaN nanowires.

6. Final Recommendation

Nanochannel glass (NCG) is a very interesting medium that appeared to have potential for photonics applications. Initial attempts to fill the channels with metals were promising. However, attempts to introduce high index materials, relative to the NCG, proved to be much more difficult. An exhaustive number of techniques were utilized in order to achieve the goal of creating a 2-D photonic crystal. In every case inhomogeneous filling of the channels was favored over homogeneous filling, i.e. nanoparticles and

nanowires. While interesting results, they were not the desired materials, i.e. homogeneous, low defect, high index materials. These difficulties were encountered for micron scale channels, and in turn, suggest that filling nanoscale channels is untenable.

The difficulties encountered are attributed to the following issues:

1. The confined geometry of the channels significantly alters the growth kinetics of materials.
2. The high aspect ratio of the channels, when taken in conjunction with (1) prohibits uniform filling of the channels from one side to the other.
3. Material used in the formation of NCG leach out of the NCG, which would be detrimental to the optical properties of the photonic crystal if uniform filling was achieved.
4. NCG is incompatible with high temperature (>400C) deposition techniques based on our studies.

The final conclusion is that NCG is not a unsuitable as a template for the construction of 2-D photonic crystals and my recommendation is to not proceed in the future with NCG for optical applications where filling of the channels with high index optical materials are required.

5. Publications

Nanoparticle Formation in Microchannel Glass by Plasma Enhanced Chemical Vapor Deposition, D. N. McIlroy, J. Huso, Y. Kranov, J. Marchinek, C. Ebert, S. Moore, E. Marji, R. Gandy, Y.-K. Hong, M. Grant Norton, E. Cavalieri, Rudy Benz, B.L. Justus, A. Rosenberg, J. Appied Physics 93, 5643 (2003).

Potassium Chloride Nanowires Grown inside Micro-channel Array Glass Using Atomic Layer Deposition, Daqing Zhang, Sam Moore, Jiang Wei, Abdullah Alkhateeb, Dev Gangadean, Hasan Mahmood, and David N. McIlroy. Aaron D. LaLonde, M. Grant Norton, James S. Young and Chongmin Wang, submitted to Applied Physics Letters.

6. Presentations

The Effects of Physical Confinement on the Formation of Nanomaterials and the Potential Towards the Realization of 3D Nanosensors, Materials Research Society, San Francisco, CA (April, 2004). (Invited)

Tantalum Oxide Nanoislands and Continuous Films Grown by Atomic Layer Deposition, The American Physical Society, Autin, TX, March 6, 2003. Abstract: Daqing Zhang, Jiang Wei, Samuel Moore, Xiangbei Chen, Leah Bergman, D. Eric Aston, Batric Pesic, and David McIlroy, *Bull. Amer. Phys. Soc.* **48**, (2003).

Synthesis of Free Standing Iron Spheres by Plasma Enhanced Chemical Vapor Deposition, The American Physical Society, Seattle, WA, March 15, 2001. Abstract:

Jason Marchinek, Abdullah Alkhateeb , Rex Gandy, David N. McIlroy, M. Grant Norton, B. L. Justus , *Bull. Amer. Phys. Soc.* **46**, (2001) 1054.

Nanoparticle Formation Using Nanochannel Glass in a Plasma Environment, Northwest American Physical Society, Portland, OR, May 30, 2003. Abstract: Ehab Marji, Dave McIlroy, Radha Padmanabhan, Hongmei Han, Rex Gandy, and Ashley Eadon.

7. Collaborations

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Wei Jiang, M.S. Physics, 2003
Pradeep Paga, M.S. Electrical Engineering, anticipated Spring 2005